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Christensen, David Johan; Andersen, Jens Christian; Blanke, Mogens; Furno, Lidia; Galeazzi, Roberto; Hansen, Peter Nicholas; Nielsen, Mikkel Cornelius

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Collective Modular Underwater Robotic System for Long-Term Autonomous Operation

D. J. Christensen, J. C. Andersen, M. Blanke, L. Furno, R. Galeazzi, P. N. Hansen and M. C. Nielsen

***Abstract*— This paper provides a brief overview of an underwater robotic system for autonomous inspection in confined offshore underwater structures. The system, which is currently in development, consist of heterogeneous modular robots able to physically dock and communicate with other robots, transport tools and robots, and recharge their batteries while underwater. These properties will provide the system, when fully developed, with unique capabilities such as ability to adapt robotic morphology and function to the current task and tolerate failures leading to long-term autonomous operations.**

I. INTRODUCTION

Offshore installations in harsh environments lead to unconventional challenges making the use of conventional subsea technology difficult or impossible. For example, at the North Sea oil platform, Siri, the discovery of cracks in the platform support structure, reducing the load bearing capability, has cost its operator approx. 500 million euros since 2009. In order to keep the platform operational, frequent robotic inspections inside the wellhead support structure are required. However, the wellhead support structure, situated at 55-65 meters depth, is a confined hollow steel structure with little space for navigation of large underwater robots. Similar challenges exist for other offshore installations, e.g. unmanned oil platforms and wind turbine parks.

In this project we address the challenge of continuous inspection and monitoring of confined subsea environments, where small, agile and dedicated robots and instruments are required. We are developing a system of autonomous underwater heterogeneous modular robots as a research platform to study adaptive, collective, distributed and fault-tolerant control in such offshore subsea operations.

The proposed system is a self-reconfigurable robot [1] which consist of several robots autonomously able to dock with each other to function as a single more functional robot with a variable morphology. Self-reconfigurable robots are potentially more flexible, adaptable, robust and versatile compared to monolithic robots [2]. However, self-reconfiguration in underwater environments has not yet been extensively studied [3]. Related underwater system includes the ANGELS AUVs which are able to dock with each other head to tail to form an eel-like robot [4] and the AMOUR system, a mobile modular underwater robot with a reconfigurable thruster configuration capable of transporting sensor nodes [5]. The rest of this paper provides an overview of the system concept and our current and future work.

Technical University of Denmark, Department of Electrical Engineering, Elektrovej, Building 326, DK-2800 Kgs. Lyngby, Denmark {djchr| jca | mb | furno | rg | pnha | miconi} @elektro.dtu.dk

II. SYSTEM CONCEPT

A. Heterogeneous Robotic System

The underwater robotic system we propose consists of several collaborative autonomous robots. The system is heterogeneous in the sense that it consists of several different types of robots including: thruster-driven swimming robots, legged inspection robots with magnetic legs for agile mobility on steel structures, stationary sensory nodes with dedicated sensors and subsea docking station to support long-term autonomous operation. The robots are able to communicate and physically dock with each other in order to collaborate and assist each other. For example, a swimming robot can transport a legged inspection robot from the docking station to an underwater oil tank for crack inspection and later bring it back for recharging and transmission of inspection data back to an human operator, see Fig. 1.

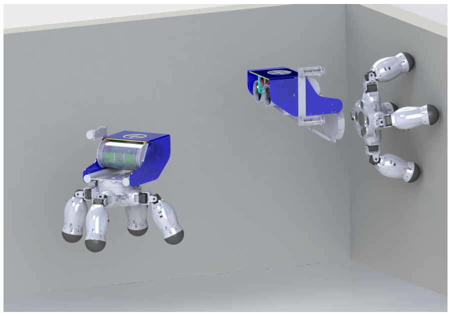
B. Modularity and Self-Reconfiguration

Unlike conventional monolithic robots, each underwater robot is in itself reconfigurable and modular. Such robots have the advantage that the modules can be reconfigured according to the particular need. This allows the offshore engineer to construct a robot on-site that matches the specific instrumentation and maneuvering requirements for the current operation. In this perspective the robotic system becomes a robotic tool kit that the user employs in order to solve a specific task. For example the robot may be equipped with a docking module, a camera module and a number of thruster modules for a specific inspection scenario and later reconfigured with a different thruster configuration and a special manipulator module for marine sampling.

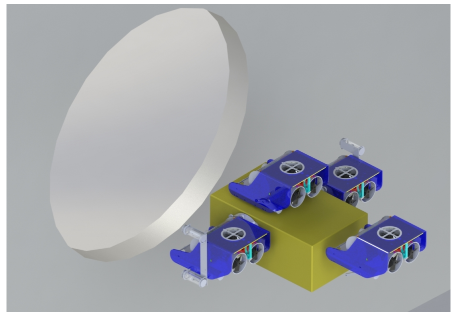
A specialized docking module enables groups of robots to self-reconfigure, i.e. autonomously adapt the configuration formed by a number of robots to a specific task-environment or physically adapt to failures of individual robots, thereby, enabling a level of self-repair.

C. Collective Control

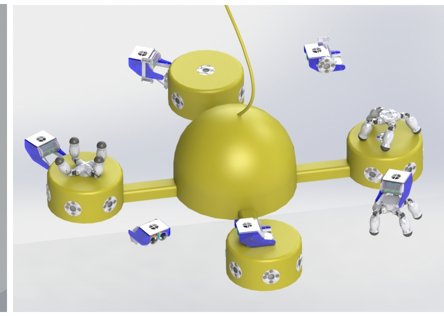
The scenario of several collaborative underwater modular robots poses numerous control challenges, including: realizing faults-tolerance and self-repair, distributed coordination and localization as well as functionality required for long-term autonomous operation. The robots will eventually be equipped with both optical devices for high-bandwidth short range communication as well as miniaturized acoustic modems for longer range low-bandwidth communication between different robots. Further, vision will be used to help localize other robots. We will develop control strategies



(a) Inspection of Subsea Structures



(b) Collective Transportation



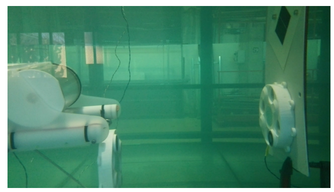
(c) Subsea Docking Station

Fig. 1. Concept pictures illustrating different scenarios with the system (note: details will change). (a) Inspection with heterogeneous robots inside support structure of offshore installation. (b) Collective transportation by multiple-robots of heavy payload through an access-hole into the support structure. (c) Subsea docking station of robots with surface based communication link with operational engineers in support of long-term autonomous operation.

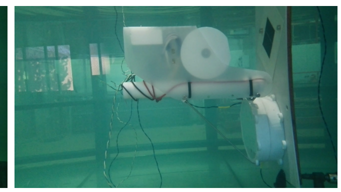
which take advantage of these limited means of coordination to enable robots to assist each other both under normal operation such as distributed task allocation as well as in failure cases, e.g. where one robot is stuck or low on battery and requires the assistance of other robots to fulfill its task objectives.

III. State of Development

Currently we have developed prototypes of underwater legged inspection robot with magnetic feet and thruster driven swimming robot. The swimming robot is a modified version of the open-source OpenROV [6] extended with a docking module, a laser range module as well as control for autonomous operation. The docking module is a unisex and 4-way redundant connector based on a permanent electromagnet which also enables docking with a metal surface and only requires energy for disconnecting. Snapshots from a docking test are shown in Fig. 2. Further, fault-tolerant control [7] based on virtual actuators for collective transportation has been developed for the swimming robots [8].



(a)



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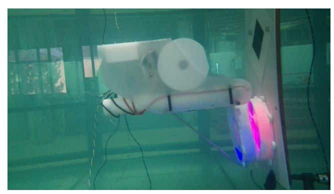
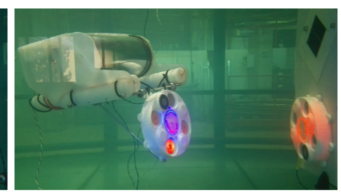


(c)



(d)

Fig. 2. Underwater robot attaching and detaching from docking module. (a) Robot approaches docking module. (b) Robot is attached and forms a strong (up to 600N) bond with the docking module without consuming energy. (c) Electromagnets in both modules are activated to switch off the permanent magnetic field (d) allowing the robot to break the connection and swim away.

IV. Conclusion

The ultimate objective of this project is to develop novel enabling technology for long-term unattended inspection and monitoring in confined subsea environments such as those found in offshore installations. In this paper we presented our approach based on a collective modular underwater robotic system comprised of heterogeneous robots. Future work will extend the current system in the directions outlined in this concept paper toward long-term autonomy, fault-tolerance, distributed control and self-reconfiguration.

Acknowledgement

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